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THE ECOLOGICAL FOUNDATIONS OF APPLIED ENTOMOLOGY.*

Stephen A. Forbes,
State Entomologist of Illinois.

It is my pleasing duty first to acknowledge the obligations of the economic entomologists of the country to this general society of American entomologists for giving this prominent place on its annual program to a topic which must, in the nature of the case, interest economic entomologists more than any one else. This is not by any means wholly an economic topic, however. Ecology is a very broad subject, extending in all directions far beyond the foundation lines of applied entomology; and successful ecological inquiry in the economic field, carefully verified as to results, as it must always be for practical use, may often suggest and illustrate methods equally useful in the other divisions of entomology, and hence of serious interest to every entomological specialist who does any thinking about his entomology.

It may well seem, indeed, that this general association of entomologists, inclusive of all specialists, is a higher court before which to bring our plea for a broadening and strengthening of the foundations and a widening of the relations of economic entomology, than an association composed only of economic entomologists themselves. There is no real separation in this country between economic and non-economic, between applied and unapplied, or even inapplicable, entomology. These interests are all so closely related and mutually

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so helpful that our two associations representing them are more like the right and left hands of the same body than two independent individuals. In bringing our difficult and important topic before what is virtually a union meeting of these two principal associations, we are simply bringing both hands to bear in the performance of a task which is too great for one hand alone.

Applied entomology is peculiarly an American subject, and here if anywhere in the world it should have accomplished its ends or should at least be in sight of its goal; and yet we have to acknowledge that, after generations of work upon them, many of the great long-standing problems of our American entomology are still unsolved, and that the people of our country are still suffering enormous losses of various description because of this fact. It is not because we do not know what we commonly call the *entomology* of the chinch-bug and the Hessian fly and the white-grubs and the cotton-moth that we are so nearly at our wit's end in our efforts to devise means for their control; it is because the knowledge of their entomology merely is not sufficient for the purpose. This line of attack was, in fact, thoroughly tested by the earlier economic entomologists of America. Harris, Fitch, Walsh, and the young Riley were entomological *observers* whose applications of entomology were mere inferences from their observations. The older Riley, Howard, and Slingerland, were among the first to make serious use in economic inquiry of the experimental method of scientific induction; and now we have a small army of workers applying their principles not only in precise, intensive work in the laboratory and the insectary, but on the broad scale of actual outdoor practice in varied environments, and on the long scale of season after season and year after year, postponing final conclusions until their premises stretch through a decade and extend over a continent.

It is when we search for specific reasons for our successes here and our failures there that we are driven to a scrutiny and analysis of controlling conditions of every description, and so find ourselves involved in studies so far outside entomology, commonly so-called, that we are obliged to apply for assistance to the physiologist, and the chemist, and the physicist, and the meteorologist, and the geographer, and the agriculturist, and

the animal husbandman, and the bacteriologist, and the physician, and the sanitarian, or, in a word, to the ecologist, who, from the nature of his studies, must, if he is thoroughly to cover his field, be something of each and all of these, and still something more.

The last and most essential phase in the expansion and development of our subject is the actual, practical, thoroughgoing *application* of the products of all our work. It is an important part of the main thesis of this address that applied entomology is not, in any practical and sufficient sense, entomology which is merely applicable but of which no application has ever been made; but that it is entomology actually applied to the protection, amelioration, or promotion of the welfare of man; and that, this being the scope of our topic, the means and methods of such application—the inducements, incitements, constraints, and compulsions necessary to a complete and effective application of the results of our entomological inquiries—are as much a part of our subject as any other; that they are, indeed, the most important—the all-important part, since without their successful use all that precedes must fail of its purposed end. Entomology which is not applied is not really applied entomology, any more than an ocean voyage which ends at the bottom of the sea is a completed voyage. We must get our ship into port and unload her cargo or we never shall be known as successful navigators, competent for continued command. We may find harbor pilots, and men at the docks, it is true, prepared and ready to take these terminal operations off our hands; but we must at least *find* the pilots and the dockmen, and in their absence we must discharge their functions ourselves.

This is an especially important point to us just now, for before we can discuss intelligently the foundations of applied entomology we must know how far the structure is to extend whose foundations we are about to plan. It is my insistent argument that it must, in the very nature of the case, cover the whole field of publication, education, community organization, coöperative effort, and legal compulsion necessary to give the fullest effect to the practical outcome of our entomological work; that our responsibilities, as official entomologists at any rate, do not end until we have done our best to see that all this is done or at least provided for. Just what

this signifies with respect to the ecological foundations of applied entomology we shall be in better position to see when we have come to conclusions as to the meaning of ecology itself, and as to the general relations of that subject to entomology as actually applied.

At this point I shall have to appeal to your courteous patience for permission to present a few elementary definitions, a rehearsal of which seems to me necessary to avoid possible ambiguity, uncertainty, or misunderstanding; especially so as the animal ecologists themselves are not by any means in exact accord as to the scope, description, subdivision, and nomenclature of their subject. Let us agree, then, that, for the purposes of this discussion at any rate, the subject matter of ecology may be defined as the relation of organisms to their environment, and that this means the *whole* environment, organic and inorganic, and any and *all* organisms, man included—man, indeed, as by far the most important living factor, from whatever point of view. And let us also understand that the relations meant are, first, relations of *interaction*—dynamic relations, of efficient cause, and effect produced upon the organism by its environment and upon the environment by the organism; second, *space* relations, of distribution, position, juxtaposition, and association—static relations, we may call these, since they show the status of an individual or a group at a given time with reference to the various objects of its environment; and third, *successional* relations, time relations, sometimes called genetic because, in showing the static relations of a group in successive periods, they trace the genesis of the present status.

It is evident at once that dynamic interaction with the environment is a *cause* of which static relation and successional relation are the *effects*. An organism comes to be established where it is, and associated as it is, by reason of the nature of the interactions between itself and its environment. If we imagine all exchange of action between the organism or the group and its environment to be suddenly stopped, we must see that the group would collapse, that the organism would promptly perish. If the system of interactions changes, the status changes to correspond, and not otherwise; and if these dynamic changes, however slow, are continuous over a long period and in the same direction, the changes of status resulting have the character of a succession.

Certainly, also, it is dynamic action and reaction between organisms and their environment which give ecology its main interest and importance. Status, genesis, and succession, organisms share with stones and soils and geological strata; but there is no ecology of such inanimate objects because they lack the intensity, variety, complexity, and quickness, of response to dynamic impression which organic ecology connotes. Water-spouts, clouds, flowing streams, winds, windmills, flames of fire and gasoline engines, are seats and centers of rapid action and reaction, but simple and uniform as compared with that of the living animal or plant. We may discuss their dynamic, static, and successional relations to their environment, if we choose, but we are agreed not to call these ecological. This is a term which we confine to living organisms; and it is indeed the special character of their reactions which enables us to distinguish organisms as alive.

Furthermore, there can be no doubt that it is primarily the dynamic factor only in ecology which interests the economic entomologist. It is only what insects do which gives them any importance to the economist, and it is only what can be done to them or about them in turn which gives applicable value to our knowledge of them and of their economy. We wish to know where they are or may be, how they are associated, and from whence they have come and by what they are likely to be succeeded, simply because their activities make them important to us. If they were inert we should not care.

I must further distinguish briefly between the ecology of a species or larger taxonomic group on the one hand and that of a local miscellaneous assemblage of organisms on the other. We may have an ecology of *Aphis maidiradicis*, for example, or of the family Aphididæ in general wherever they occur; and we may also have an ecology of all the inhabitants of the cornfield considered as a group of plants and animals associated in a natural habitat. From this point of view, we see applied entomology especially interested, sometimes in associational or habitat ecology, such as that of the household insects or the insects of the forest or the truck-farm or the orchard, and sometimes in species ecology or taxonomic ecology—that of a single economic insect species, for example, or that of the insect associates of a single crop plant, or the several mosquito species serving as carriers for a single disease-producing parasite.

And now what shall we say of that view of ecology by which man, with his unrivalled powers of action and influence—the center and source of the most amazing interactions ever known between an animal species and its environment—is left practically outside the natural system, or is looked upon at best as a merely monstrous overgrowth of it—a *pathological* influence, a destructive enemy of nature, all whose works are *artificial* as compared with the *natural* effects and products of the vital activities of ants and caterpillars and crawfishes. There are ecologists to whom primitive nature is the earthly paradise, and civilized man is a kind of fiend, a Satan bent upon its destruction—a triumphant Satan who seems bound to reduce the whole earth, except, perhaps, the national parks, zoological gardens, bird preserves, and the like, to conditions as unnatural, as abnormal, as those of a prison or a hospital. Their ecology is a system not of this present time but of the world before Adam, before the fall of man had introduced into the world the germs of that fatal and frightfully contagious disease known as civilization.

And there are entomologists whom any trace of humanistic values in their entomology seemingly repels almost like a taint of disease or decay. They remind one of the famous English mathematician who is reported to have said that he thanked his God every day on his bended knees that he had never discovered anything useful. This attitude is of course their privilege, as a matter of personal choice, just as it is the privilege of the ecologist to specialize in the field of uncivilized nature, or of the paleontologist to study a vanished system of life by means of its fossilized remains; but to represent these divisions of the subject as any more normal or natural or important than that phase or stage of the natural system which embraces civilized man, is not only misleading but, in my judgment, injurious. The ecological system of the existing twentieth century world must include the twentieth century man as its *dominant* species—dominant not in the sense of the plant ecologist, as simply the most abundant—for which idea *prevalent* would, I think, be a better term—but dominant in the sense of dynamic ecology, as the most influential, the controlling or *dominant* member of his associate group.

In applied entomology this is all of course very obvious, and needs no elaboration; for the economic entomologist is an ecologist pure and simple, whether he calls himself so or not—a student primarily of the interactions of insects and men, of that part of the actions and ecology of insects by which the welfare of man is affected, of that part of the ecology of insects which overlaps upon the ecology of man and that part of the ecology of man which overlaps, or can be profitably made to overlap, upon the ecology of insects. And it is the human interest which predominates and controls; the motive to applied entomology is primarily humanitarian. If there were no human interest to which entomology is applicable, there would be no applied entomology.

Now, since the field of applied entomology is precisely and solely that part of ecology in general over which the ecology of man and that of insects is coincident; since it is simply the ecological area common to two classes which differ almost immeasurably in their endowments, general interests, and natural relations, it must be evident, *a priori*, that a knowledge of the broad field of ecology as a whole, and of its general aims, principles, processes, and products, is fundamental to the special studies of the economic entomologist. It is only in some such sense as this that we can properly speak of the "ecological foundations of applied entomology" at all. The very substance of applied entomology being ecological through and through, it can have a foundation in ecology only as a part is founded upon the whole, as an apex is founded upon a base, as special aspects and applications of a subject are based upon its general principles and its most comprehensive characters. It is my special task, therefore, to point out and illustrate some of the ways in which general ecology may be made helpful to applied entomological ecology, and, *vice versa*, ways in which applied entomology may be made useful—is already useful, indeed—to the student of general ecology.

A distinguished dean and professor of agriculture in one of our leading universities told me quite lately that the great need of practical agriculture at the present time is nothing less than a scientific study of vegetable physiology—the physiology of the common crop plants—concerning which we know so little that is exact and exhaustive that even the so-called scientific

farmer is still practicing his art in great measure as did his remote predecessors, by rule of thumb. He paid us the compliment of saying that the economic entomologists of the country are much farther advanced in this respect than the agronomists—that we know more of the corn insects than the corn breeder knows of the corn plant. I did not tell him, as I might have done, that this opinion simply signified that he knew less of entomologists and the state of their knowledge than he did of corn and the corn farmer; for this is also our case. How many of our measures of protection and defense against insect depredations depend upon any precise knowledge of general fact or scientific principle, or are traceable to anything better than a purely empirical warrant? If we attempt to analyze what we know and what we still need to know concerning any one of the great insect pests before we shall be in a position to do all that can be done and ought to be done to restrain its ravages and injuries either by measures of avoidance, prevention, mitigation, or arrest, we may perhaps get a clearer, concrete idea of what is involved in economic entomology, and what are the foundations of fact and principle upon which it rests.

The chinch-bug of our western grain fields has been a subject of close, though inexpert, observation for nearly a century, and of much expert study and experiment for more than a generation; but during this present year, in my own state, where we have used against it every method and device which we could induce those most immediately concerned to apply, millions of dollars worth of farm crops have been destroyed by it, and a large part of the rural population of whole counties has been brought close to economic distress and in some cases to financial ruin.

We know the facts concerning the geographical distribution of this insect species, without which, of course, we should not know where to expect its ravages and to provide against them, but this is for us a matter of observation merely, and not of scientific inference or rational interpretation; we do not definitely know what are the *limiting conditions* of its distribution in any direction. Over parts of its occupied area it is present only in numbers economically insignificant, and we have little actual knowledge *why* it is destructive in a part of its territory

and not elsewhere. Still less do we know just why the boundaries of its area of destruction fluctuate in its various outbreaks, or why the foci of its injuries shift from place to place in successive years.

We know that such an outbreak or uprising is commonly preceded by widespread drouth for two or more years, and that as a rule its disappearance follows upon a season or more of comparatively wet weather, especially at its hatching time; but we do not know enough of other agencies contributing to either movement to give us means of either explanation or prevision; and of the climatic or meteorological agencies which seem to produce these effects, we do not know how or why they produce them, whether by some direct action upon the physiological or reproductive processes of the insects themselves, or indirectly through effects produced upon the food plants of the species, or upon its disease germs, or upon its newly discovered egg parasite, or upon several or all of these at once, together with other agencies as yet unknown.

Concerning its single known effective insect parasite, discovered only last year, a species which seems to have specialized upon the chinch-bug's egg, we know that its rate of multiplication so far surpasses that of its host that under favorable conditions it may rapidly overtake the latter and reduce an outbreak to insignificance—an apparently available weapon of first-class importance which has been made ready to our hands; but just what *are* the conditions favorable to its appearance, spread, and rapid increase, and whether these processes can be hastened artificially or not, of this we know nothing. We do not even know concerning this or any other parasitic insect how the parasite and the host are brought together in the field, whether because they have been so similarly tuned and timed to their environment that they find themselves brought into each other's neighborhood automatically, because of like reactions to their surroundings, or by some more occult and less certain process.

We know that at the beginning of a chinch-bug outbreak fungous disease seems to have little or no effect upon the rapidly multiplying hordes, but that when it is declining they sometimes burst forth like a flame in dry fuel. We have strongly suspected that this is due to a diminished average

vitality in the victims, but we can only guess at possible causes of decrease in their powers of resistance; and of these disease-producing fungi we know too little, either of their effects, of the comparative virulence of the various species, of variations in the virulence of different strains of the same species, or of the possibility of increasing their effect by selective cultures of the most virulent varieties.

We know that the chinch-bug is strictly limited for food to plants belonging to the grass and sedge families, but we do not know why it can not feed—refuses even to try to feed—upon other plants, although prompt starvation is the alternative; nor do we know why it plainly prefers some of its natural food-plants to others, and why it thrives best and multiplies most rapidly upon those which it prefers. We do not even know by what tests or senses it distinguishes its favorite foods or avoids those upon which it can not live.

We have noticed, where this insect sweeps in hordes across a field, infesting all plants substantially alike, that here and there one may stand alive and erect while all its companions have perished; but we do not know why this should be so or whether by a selection of such escaping victims we might breed repellant or resistant lines, increasingly capable of withstanding attacks destructive to the average of their kind.

We know the ordinary life history of the chinch-bug fairly well, although our knowledge is still lacking in the details of variation of life history in different regions, seasons, and climates; while of its so-called physiological life history we know almost nothing exact.

We know that an invaluable opportunity is afforded us at harvest time to destroy the pest as it attempts to escape on foot from the dry wheat stubble. We know that a line of crude creosote poured upon the ground is practically impassible by it, and that this simple fact of ordinary observation may be utilized to arrest its dispersal and, by the addition of post-hole traps along the line, to capture and destroy it by bushels and barrels and even by wagon-loads; but we do not know what it is in the creosote line which makes it seemingly impassible, since occasionally, or under extraordinary compulsion, the insects cross it without the slightest injury. Consequently, in our search for more desirable substances for this use we have

to pick and choose at random, being quite without the guidance of any general knowledge of the physiological sensibilities of the species.

We know that certain insecticide substances in solution or emulsion are effective against it in a way to make them practically available, but we do not know how or by what properties they produce their fatal effects and we are consequently without definite guidance in our search for other such insecticides.

We know that any and all measures against this insect are of comparatively little avail if undertaken sporadically, by an individual only here and there; that for their fair and full effect they must be made the fixed policy and practice of whole communities, actuated by the community motive as well as the personal one. We know indeed that a large part of our applied entomology fails of its application because communities are not brought to the point of coöperative action in the general interest; but we do not know—we have scarcely discussed among ourselves—the best means of appeal and the best methods of organization and management to effect these results, without which much of our economic entomology must fall practically short of the economic end.

We realize that the actual utility of all our work depends upon a general knowledge of its practical product, and of possible methods of its utilization in every case arising, and on an exercise of a sound judgment in the adaptation of such methods to the conditions of the time and place; but we are far from any kind of satisfying success in making such knowledge the common property of the people most concerned and in training and assisting the common judgment to make the best use of the knowledge they possess.

We well know that no people can be brought to do spontaneously all that they ought to do in our field in the common interest, and that education, persuasion, encouragement, incitement, and organization even, must be supplemented by legal requirement and by law enforcement if the people are not to suffer clearly avoidable losses of property, comfort, health, and life itself, due directly to insect infestation, and we have made considerable progress of recent years in securing legislation, state and national, in some parts of this field; but it still

remains true that the land owner who may be sued for damages if he permits his horse to break into his neighbor's garden is not even liable to reproof if he raises caterpillars in armies, Hessian flies in swarms, and hordes of chinch-bugs, to destroy his own crops and then to spread throughout his neighborhood as a general menace and calamity.

And so I might go on to enlarge my list of things done and things remaining to be done in various other lines of effort and activity if we are to do all that is needed to make our entomology applicable, and to secure the application of it. But I have gone far enough to illustrate the fact that the useful things we know and those we still need to learn are practically all items in the physiology and ecology of our injurious species, and that the physiological items are of practical interest to us solely because of their ecological significance. Even the human factors of our economic problem are really ecological, for they have to do with the relations and interactions of men among themselves, as affected by the relations and interactions between themselves and their insect enemies.

If you ask me now whether we should be any nearer the practical control of our most dangerous and destructive insect pests if we had the details of their ecology well worked out, I shall have to answer that I do not know, any more than the entomologists who studied the habits and general ecology of mosquitoes foresaw the use of their observations as an indispensable link in the study and control of malarial disease—any more than Laveran knew when he found a blood parasite associated with malarial disease in man that the remaining links in the chain would presently be traced.

We can have, in fact, no better illustration of the economic value of ecology than this subject of insect-borne disease, the one of its kind which by the joint labors of entomologists, parasitologists, physicians, legislators, and administrators has been brought to the point of a scientific and practical success, perhaps the most remarkable and the most nearly complete of any achievement of applied entomology. Let us make of this a sample and test of successful research, distinguishing the successive stages in the discovery of the nature of malarial disease and the modes and means of its propagation—the joint conquest, as Sir Ronald Ross remarks, of medicine and zoology fighting side by side.

There was, to begin with, a general background of knowledge, variously acquired, of the parasitic relationship—the relation of internal parasite and animal host—a purely ecological subject. Next in logical succession came the question of the paths and modes of transmission by which a parasite passes from host to host—again an ecological inquiry, in the course of which it was found that some parasites require two kinds of hosts in alternation for the completion of their life histories, and that these two hosts are usually—almost necessarily, indeed—animals ecologically associated. In rational but not chronological order, then follow (2) the discovery of *protozoan* parasites, eventually including a blood parasite in man invariably associated with malarial disease, and a special study of the habits and development of this parasite in man; (3) prolonged but vain search for it outside the human body in situations where malarial disease was prevalent; (4) the suggestion of mosquitoes as possible carriers of the malarial poison, a hypothesis based on the coincident distribution of mosquitoes and malaria; (5) experimental tests of this hypothesis by the feeding of mosquitoes with blood from malarial patients, and search for the human-blood parasite in their bodies—experiments which were successful when the right species of mosquito were chosen; (6) studies of the life history of the parasite in the mosquito's body; (7) successful experiments in the inoculation of man with malarial disease by means of mosquitoes containing the malarial parasite; (8) field studies of the precise distribution and reproductive habits of Anopheles; (9) experiments with practical measures for the local control of malarial disease by an elimination of the breeding places of malarial mosquitoes; (10) the construction of a program of practical operation and requirement for the local abolition of malaria; (11) the passing of ordinances and the issuing of orders for the execution of this program; and finally (12) the organization and management of a competent executive force, with authority sufficient to carry such a program out effectively. Thus was accomplished the virtually perfect result in Panama; and by a duplication of these methods, so far as they were applicable to a disease whose germ has never yet been seen, yellow fever was also mastered.

In all this series it is the *last* step which costs; the malarial parasite and the mosquito are less refractory to the control of man than man himself; it is less difficult to perfect methods for

preserving life and health than it is to induce the threatened victims to make use of them effectively. So true is this, even with respect to malaria, that Sir Ronald Ross has said, in an address delivered in London a month ago, that although fifteen years have elapsed since the essential discoveries were made, not more than a tenth part of the possible benefit to human life has been effected, and that this is only because mankind has not put its heart effectively into the business. In the purely economic field also this is equally true, and in my own state further progress in the control of the chinch-bug and the corn root-aphis seems to be blocked, as by an impassible stone wall, by the disinclination of the people most immediately concerned either to do voluntarily or to permit themselves to be coerced into doing the necessary right thing in their emergency. They would rather do as they like to their ruin than to be commanded, and perhaps compelled, to do as they ought for the salvation of themselves and their communities.

Both of my foregoing illustrations, one of a complete and the other of an incomplete investigation, show us how thoroughly ecological applied entomology is in its distinguishing characters; but they do not sufficiently distinguish specific ecological detail from general method and principle, or give us any convincing evidence of the advantages which applied entomology may hope for in the work of the general ecologist who seeks only to develop his subject in the broad way, with no special thought of useful applications.

For this we need only to recall what it is that the general ecologist undertakes to do. For us as students of applicable entomology and of the means and methods of its application, the question is, in general terms, whether it would help us in our special work if we knew in advance, or could readily learn, the essential facts concerning the environment of the animals or plants in which we are especially interested; if we knew the topography of the environment, its hydrography, and its climate, as these are now and as they were before civilized occupancy; if we knew about the water supply, the drainage, the past and the present levels of the water table, the soils and their distribution, and the effects upon these of occupancy and use, present, past, and prospective; if we knew the details of the ecological structure of the region, and the probability of changes in such structure under gradually intensified human use; and

if, among many other particulars the mere enumeration of which would quite exhaust your patience, we knew the facts concerning the temperature, light, and moisture of the air in different situations at different levels and during all seasons of the year.

None of this matter is entomology, but it, and very much more of the kind, is entomological ecology, because it is an indispensable part of a description of the ecological environment of insects—of that part of the physical environment which enters into relations of cause and effect with the insect species which it environs.

Would it not further help us greatly if we knew, or could readily learn in advance, even the more general facts concerning the reactions of insects and groups of insects, especially the economic species, to these various factors of their environment, as worked out under precise experiments verified by observations in the field—their reactions in their several generations and in the various stages of their life history—and the effects upon their welfare of natural variations in these several environmental factors; if we knew also much more than now of the general relations of insects to the other organisms of their neighborhood, especially to those upon which they feed, and of the relations of *these* organisms and their products to the several factors of the physical environment?

To me it seems so evident that such a knowledge would be of the greatest value to the investigating economic entomologist, that I am quite prepared to paraphrase the statement of Dean Davenport concerning the agricultural need of vegetable physiology by saying that the greatest need of applied entomology at the present time is just this kind of scientific ecology, and that it is among our first and most important duties to acquaint ourselves with this field and to encourage, provide for if possible, and assist as we can, serious, exact, and thoroughgoing work in scientific entomological ecology.

It is now time, indeed, for me to say that entomologists in general are not lacking in an appreciation of these facts or in a cultivation of these interests; that, without waiting for the ecologists to bring grists to their mill, they have gone out into the fields and have harvested and threshed much grain for themselves; that they have of recent years done considerably more, I think, in entomological ecology than has been done by

the professed ecologists, and that they are quite disposed to meet the latter gentlemen a very liberal halfway in the exploration and exploiting of their common territory. It is something of an obstacle, to be sure, to a coöperative understanding of these two groups that they look in opposite directions, and thus approach each other backwards, the economic entomologists being interested primarily in conditions as they are and may be made to become, referring to the past only for clues useful in the solution of problems of the present and the future, while the pure ecologists are looking rather to the reconstruction of a vanished or vanishing past, and tracing ecological history as far back as their data will permit. Each of these two groups is performing, indeed, its most essential function; but it will certainly be to the advantage of both that they should understand each other and should make the cross-connections necessary to enable each to apply the other's products and to avail itself of the other's services.

It will help us perhaps to a clearer idea of just what kind of ecology is most needed in applied entomology if we see what, in general, the economic entomologists have lately been doing in the ecological field. A survey of reports and papers which have appeared in quite recent years will show us that, in addition to the kinds of ecological data which have now become standard in discussions of economic species, there is a considerable quantity of most interesting new work being done by entomologists on the effect of variations in temperature and moisture upon the metabolism, reproduction, and life history of insects—virtually an attempt to isolate the elements of weather and climate and to experiment with them separately as preliminary to experiment with the various combinations of them present in nature. These are the first steps in a very long road, with branches running in many directions.

Pursuing one of these branches a few years ago I found myself on the boundary line of vegetable physiology, where I was fortunate enough to meet a botanical ecologist willing to go my way, and to him I was permitted to turn over the inquiry I was making, with a result, lately published in a doctor's dissertation at the University of Illinois, that the reason why I was sometimes driving injurious insects away from corn hills, with no injury to the seed or plants, by a preliminary treatment of the seed with repellant oils, but sometimes, on the other

hand, was injuring or killing the corn, was because the permeability of the coats of the embryo of the corn plant to oils varies with the amount of moisture in the kernel, the wet corn kernel absorbing these oils quickly to the injury of the plant, while the relatively dry kernel absorbs them slowly, with no injurious consequences. My discrepant results were thus due to mere differences of weather at planting time in the several cases.

The kind of ecology which entomologists, intent on the solution of their special problems, are *not* now undertaking—are scarcely in a position to undertake—is the formulation and elaboration of general principles—the laying of foundations broad and deep. For their emergency structures, they are digging down a little way as well as they can, or are merely building, perhaps, on the bare ground. But this is because the ecologists have not yet built—are only beginning to try to build—foundation structures up to their level. When the ecological foundations are well and truly laid, then our entomological superstructures will rest upon them, as a matter of course.

Associational ecology, a favorite subject with the pure ecologists, is another division to which entomologists have thus far given little attention—too little, I think, for their own good. Even where we treat in a comprehensive way of all the insects infesting a single crop plant—deal, that is, with a mixed association in which the crop plant is the prevailing, central species—we pay little attention, as a rule, to the ways in which the different insect members of the group interact with each other, unless, indeed, they are parasitic or predaceous.

Pardon me if I draw once more upon my own experience for a simple illustration of the relations which may be made out by a comparison of the data of associated species. It was in a study, made more than thirty years ago, of the insect population of a strawberry plantation that I noticed the curious way in which three species of coleopterous larvæ succeed one another in their injuries to the roots of the strawberry plant, the life histories of the three being so adjusted, as by a kind of dovetailing process, that simultaneous competition is completely avoided, each species appropriating its share of the growing rootage of the plant in its turn, and all thus drawing from it a much larger food supply than if their drafts had been coincident. This fact was the more striking when it was seen that

one of these so-called root-worms differs so widely in its life history from another species of the same genus, living in the same territory but upon another food plant, as to suggest an actual fitting of it in, by a process of natural selection, to the period left vacant for it by its two companion root-worms of the strawberry field.

Ecological succession has also its points of contact with economic entomology, as is being shown at this very meeting of the Association of Economic Entomologists, in a paper by one of our leading zoological ecologists.

If, now, I may apply my own description of ecology, as inclusive not only of all kinds and grades of interaction between men and insects but also of all interactions among men which have insect activities as their cause, I may conclude this outline of my subject by brief reference to the things which our countrymen ought to be induced to do in each other's interest as well as in their own. The great obstacle to a reasonable success is, as I have already intimated, a deficiency of the community spirit in the American community. If our people had, as a mass, a fair equivalent for the disposition to social cooperation, to social service, to social sacrifice when sacrifice is needed, that is exhibited by some of their insect competitors, our conquest of the insect world would be relatively easy. In that case, whenever a community was threatened with a destructive insect outbreak, it would react unanimously, effectively, and at once to the warnings of its posted sentinels—its official economic entomologists. Knowing itself to be without the inherited automatic machinery of coöperative action which makes a hive of bees or a colony of ants a unit when its welfare is threatened, it would provide itself in advance with artificial substitutes for this constitutional system. It would equip itself and its progeny with the necessary practical knowledge, it would cultivate by all possible means the necessary public spirit, and then it would surround itself with laws and ordinances and provide itself with officers, to the end that it might be constrained to do, even against the will of many of its individuals, what under like circumstances a family of social wasps would do because it could not help itself. Taking a lesson, in other words, from insect ecology, it would contrive to do by the aid of rational intelligence, forethought, and will

at least as much for the common welfare as the insect does in the interest of its kind under the impulse of a wholly ignorant instinct.

I venture now to hope that I may have made by this time a sufficient showing of the fundamental nature of the connection between ecology and applied entomology to justify a few closing sentences upon the educational bearings of my conclusions. If applied entomology is essentially a mixture of human and insect ecology, then it seems clear that courses in general ecology should form a part of the education of the economic entomologist. Indeed, I have much tangible evidence of the value of this combination in the results shown in my own university department of entomology, whose more capable students all tell me of the unique advantage which they find in ecological courses because of the broader outlook and the new point of view which these give them, and especially because of the greater theoretical interest of their technical studies when related to the foundation principles of ecology. The ecological environment is a complex of causal agencies, without an analysis and interpretation of which an adequate knowledge of causes in biology is impossible.

I believe that students of ecology itself would be equally, although somewhat differently, profited if they were to take one or more economic courses in entomology; that they too would find a new outlook thrown open to them and a new and larger meaning given to their work. I hope that the time may soon come when ecology shall be taught in at least every state university and every agricultural college, and when something of applied biology shall be included among the regular courses of every university student specializing in ecology. Then for the first time we may be in a position to estimate fairly the value of the contributions which entomological ecology, fully and thoroughly applied, may be competent to make to the progress of biology and to the welfare of civilized man.

Urbana, Illinois, December, 1914.